Concrete Arch Bridges

The advent of modern concrete technology fostered a renaissance of arch bridge construction in the United States. Stone arch bridges constitute an important chapter in American bridge building, but by the second half of the nineteenth century the labor-intensive nature of masonry arch bridge construction contrasted unfavorably with the ease of metal truss erection. Reinforced concrete allowed the arch bridge to be constructed with much more ease than ever before and maintained the load-bearing capabilities of the form. Accompanying the return of the arch form were the traditional architectural decorative details that had been in abeyance during the heyday of the truss bridge. It is interesting that the renaissance of the arch bridge and its decorative elements coincides with the reintroduction of the beaux arts aesthetics following the 1893 Columbian Exposition.

Concrete arch bridges are classified into four groups based on the way the dead load of the structure is carried. The four groups are (1) filled spandrel, (2) closed spandrel, (3) open spandrel, and (4) through arches. The filled spandrel arch consists of a barrel arch which carries filling material and terminates in closed longitudinal walls that act as retaining walls for the fill. Both closed and open spandrel arch types carry the roadway loads to the arch ribs and contain no fill. The former type carries the deck loads by spandrel walls resting on the arch ribs, while the latter type carries the roadway loads to the arch ribs by spandrel columns. Through arches consist of ribs which extend above the roadway and carry the deck loads by vertical hangers (Plates 13 and 14).

PLATE 13: **Typical Concrete Closed Spandrel Arch Bridge: Bridge at Burnt Mills** SOURCE: MDOT Photographic Archives (Hughes Co. Photographers, 1931)

PLATE 14: **Typical Concrete Open Spandrel Bridges Under Construction: Bridges on Loch Raven Boulevard in Baltimore**

SOURCE: MDOT Photographic Archives (Hughes Co. Photographers, 1933)

Early concrete arch bridges were governed by building traditions of their predecessor, the stone arch. They were shaped as traditional masonry barrels with solid, filled arches; surface treatment of important bridges incorporated stylistic "stones" such as incised voussoirs or keystones. The first known reinforced concrete arch bridge in the United States was designed by Ernest L. Ransome and built in 1889 in Golden Gate Park, San Francisco (Armstrong 1976:115; Plowden 1974:298). It was reinforced with rods or bars, probably of the twisted type patented by Ransome in 1884, and scored to imitate stone.

As the structural advantages of reinforced concrete became apparent, the heavy, filled barrel was lightened into ribs. Spandrel walls were opened, to give a lighter appearance and to decrease dead load. This enabled the concrete arch to become flatter and multi-centered, with longer spans possible. Designers were no longer limited to the semicircular or segmental arch form of the stone arch bridge.

The variety of arch types made possible through reinforced concrete design is exemplified by the designs of Daniel B. Luten, whose patented bridges were built throughout the eastern and midwestern United States. Luten was an 1894 civil engineering graduate of the University of Michigan. Upon graduation he was retained at Michigan as an instructor and assistant to Professor Charles E. Greene, whose arch analyses were noted in the ASCE *Transactions*. From 1895 to 1900, Luten was instructor of civil engineering at Purdue University and in 1900 he resigned to design bridges. One year later he was designing and patenting his designs.

In 1899, Luten applied for a patent for an arch bridge of concrete, stone, brick, iron, or steel in which ties were placed below the water, from abutment to abutment to resist the arch thrust, and the patent was granted on May 15, 1900. His ties, "which may be made of any material—as wood, iron, or steel—but in this case are shown as being made of wood or timber, as this is the best material now known to me for the purpose, it being practically everlasting when used under water." This concept developed into his patent for a tied concrete arch in which steel tie rods were embedded in a concrete pavement across the streambed. A 1906 text on reinforced concrete by Albert Buel described Luten's steel-tied, paved arch bridge.

Luten's 1907 patent No. 857,920 shows a barrel arch with recessed panel parapet walls and a similar "flat arch or girder" type design with the same parapet detail. A similar patent of 1907 lightened the bridge dead load with open spandrels but maintained a barrel arch.

In 1907, Luten patented another arch type which reinforced the arch barrel transversely as well as longitudinally. In effect, this design was a stiffened

spandrel which permitted thinner arch sections. Included in this patent were several variations, one of which made parapet walls act with the superstructure to carry the loads. In patent No. 853,203, this variation was described as follows:

> A concrete bridge having a roadway bordered by a concrete wall, a longitudinal reinforcing member embedded in the walls, and transverse reinforcing members embedded in the wall and extending into the bridge under the roadway.

Other Luten patents, totaling over 30, included numerous variations, among them a hinged arch and viaducts; systems of reinforcement; ingenious centering forms and methods; methods of bridge construction; and reinforced concrete beams.

Daniel Luten was also an enthusiastic salesman of his bridge designs, emphasizing their advantages both in company catalogs and at professional presentations. In the American Concrete Institute *Proceedings* of 1912, he praised concrete arches:

> Concrete as a structural material is full of surprising possibilities and one of these is that the most beautiful and appropriate applications of concrete to bridges, that is in the arch form, is also the most satisfactory from almost every engineering standpoint [Luten 1912:631].

Luten's first bridge company was the National Bridge Company, established in 1902. A 1914 Luten publication stated that until 1905 the National Bridge Company did the contracting and constructing of its bridges, but after that it was involved only in engineering design and supervision. In 1907, a company catalog advertised a variety of earth-filled arches reinforced with steel rods. It claimed that the company had designed more than 700 bridges of this type. An interesting arch type included in this 1907 catalog was the "arch-girder" bridge, described as a flat arched floor supported on five girders.

By 1911, Luten had won national attention, and was singled out by bridge historian Henry Grattan Tyrrell as a "designer and builder of many fine concrete bridges throughout America" (Tyrrell 1911).

Luten and other bridge engineers designing concrete arch spans were directly influenced by the City Beautiful movement, an early twentieth century effort to advocate construction of public and municipal structures that were aesthetically pleasing yet still functional. The increasing popularity of gracefully curved arches and ornamented concrete parapets also reflected the early twentieth century promotion of City Beautiful ideas and goals among urban planners, highway engineers, and motorists' groups like the American Automobile Association and the Lincoln Highway Association.

A 1917 publication entitled *Reinforced Concrete Bridges* by Daniel B. Luten, "designing and consulting engineer," illustrated a broader range of arch types, although still based on the same theme as his earlier designs. In this catalog, bridge illustrations ranged from long-span, high-level open spandrel arches to small highway bridges. Luten contrasted a "Highway Bridge of Plain Design" with a "Park Bridge of Attractive Design" in the same publication. The parapet wall of the highway bridge was a solid recessed panel and that of the park bridge a balustrade type (Luten 1917).

By 1919, Luten claimed to have designed some 17,000 arches, and stated that examples of his designs could be found in all but three states of the Union. Indiana alone had some 2,000 Luten arches. Luten arch bridges known to have been built in Maryland often featured curved, simply ornamented solid parapets. Characterized by the graceful arch and curved, incised solid parapets, this bridge type was described in Luten Company catalogs as "Highway Bridge of Plain Design." This type of concrete arch was widely built as a proprietary type in the first quarter of the twentieth century. Luten's "Park Bridge of Attractive Design" also influenced concrete arch design in Maryland. Variations in the Luten style arch and parapet detail soon developed and resulted in similar nonproprietary designs prepared by highway department staffs.

Simultaneous with the development of Luten's patented types, another form of reinforced arch rib emerged, the through arch. The two arch ribs of this type rise from piers and carry the deck on vertical members suspended from their crowns. They are sometimes referred to as "Rainbow Arches" and sometimes as "Marsh Arches" after German-born engineer, Marsh, who patented his through arch and built it between 1912 and 1930.

The procedure for constructing concrete arch bridges was roughly similar to that used for stone arches. In the first phase the foundations, abutments, and piers were constructed. Next, temporary bracing or centering, also used as forms for the concrete, was erected followed by placement of reinforcement. The concrete was then placed in the forms symmetrically from each end moving in toward the crown. Longer spans, more than 80 feet, had to be poured in sections, but shorter spans could be completed in one pour. The spandrel walls, posts, or arches were formed after the arch ring was completed. The centering was gradually released after the concrete had set sufficiently, usually within the standard twenty-eight days but depending on conditions. After the formwork was removed the concrete surface was finished according to various methods. Sometimes a facing was applied as in brick or stone. Often monumental bridges had surface treatments imitating stone. If the surface was to be left exposed then it was either rubbed to produce a smooth surface or worked with tools to produce a texture.